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Title of Research: **"A SADAP Study of the Interstellar Medium of the Large Magellanic Cloud"**

Principal Investigator: David J. Helfand
Professor of Physics

Period Covered by Report: 1 August 1987 – 31 July 1990

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FINAL TECHNICAL REPORT FOR NAG8-664

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Research Goals and Summary

The principal goal of the proposal "A SADAP Study of the Interstellar Medium of the Large Magellanic Cloud" was to use the imaging survey of the Cloud conducted by the *Einstein* Observatory in conjunction with other space astronomy data to construct as complete a picture as possible of this galaxy's ISM for use in constraining global ISM models. The project required extensive development of calibration, flat-fielding, decontamination, and mosaicing algorithms for application to data from the *Einstein* imaging proportional counter so that low-level diffuse X-ray emission could be studied for the first time with that instrument.

The project was a success. We have detected and characterized the hot ISM in the LMC, including both the role it plays in the energy balance of the galaxy as a whole and the dominant effect it has in regulating star formation on intermediate ($\sim$ 1 kpc – superbubbles) and small ($\sim$ 100 pc – stellar wind bubbles and OB associations) scales. The results of this work have been written up for presentation in five refereed journal articles and three conference proceedings; abstracts of the principal papers are given below. This work also comprised the bulk of the Ph.D. dissertation for Dr. Qingde Wang a graduate student in the Astronomy Department at Columbia University. Dr. Wang defended his dissertation in May and has now taken up a position at the University of Colorado as one of the first Hubble Fellows.

Abstracts of Papers Published, In Press or Submitted:

1. The Hot Interstellar Medium Toward SN1987A

Qingde Wang, Thomas Hamilton, and David J. Helfand

ABSTRACT

An X-ray image of the field surrounding SN1987A, derived from the *Einstein* Observatory Large Magellanic Cloud Survey, has allowed us to constrain the properties of the hot ionized medium (HIM) along the line-of-sight to the supernova. In particular, we find that if the absorption feature observed in the optical spectrum of SN 1987A at 6379.7 Å is identified with [FeX] λ6375, an extraordinarily high iron abundance must be present, either in the hot interstellar medium of the LMC or in coronal gas between that galaxy and the Milky Way. Measurements of the temperature and density of the hot gas derived from the X-ray data combined with estimates of the heating rate and the maximum plausible enrichment of the ISM by supernovae lead us to conclude that the identification of the line as [FeX] is probably in error.

2. The Detection of X-rays from the Hot Interstellar Medium of the Large Magellanic Cloud

Q. Wang, T. Hamilton, D.J. Helfand, and X. Wu

ABSTRACT

We present a comprehensive reanalysis of the *Einstein* Observatory imaging survey of the Large Magellanic Cloud. Techniques necessary for the study of faint diffuse X-rays, including the decontamination of images from solar scattered X-rays, are described in detail. A discrete source search of a $\sim$ 37 deg^2 region in the vicinity of the LMC reveals 105 sources, 33 of which are reported here for the first time. About half of the sources are clearly identified with objects in the LMC, while the remainder are shown to be predominantly foreground stars and background AGN. Subtraction of all discrete emitters reveals extensive diffuse X-ray emission associated with the LMC. The spectrum of this emission is well fit by an optically thin thermal plasma with temperatures ranging from $\sim 2 \times 10^6$K in the western part of the galaxy to $\sim 10^7$K in the vicinity of the active star formation complex near 30 Doradus. An anticorrelation of HI and diffuse X-rays on scales of $\lesssim 1$ kpc is consistent with a picture in which superbubbles of hot gas are created in the neutral ISM by the combined action of stellar winds and supernovae in massive stellar associaitons. Over a substantial fraction of the galaxy, the hot ISM is seen to have an emissivity and pressure significantly in excess of that in the medium surrounding the Sun. Estimates of the cooling and heating rates for the hot gas suggest that a substantial fraction of the energy input from stellar winds and SNe either radiates in other wavelength bands or leaves the galaxy in the form of a wind. The prospects for using the LMC as a testbed for global ISM models is briefly discussed.

3. An X-ray Image of the Violent Interstellar Medium in 30 Doradus

Q. Wang and D.J. Helfand

ABSTRACT

We present a detailed analysis of the X-ray emission from the largest HII region complex in the Local Group, 30 Doradus. Applying a new maximum entropy deconvolution algorighm to the *Einstein* Observatory data, we find striking correlations amongst the X-ray, radio and optical morphologies of the region, with X-ray emitting bubbles filling cavities surrounded by Hα shells and coextensive diffuse X-ray and radio continuum emission from throughout the region. The total X-ray luminosity in the 0.16 – 3.5 keV band from an area within 160 pc of the central cluster R136 is $\sim 2 \times 10^{37}$erg s^{-1}. The temperature of the X-ray emitting gas is $\sim 5 \times 10^{6}$K. This coronal component has a total thermal energy of $\sim 3 \times 10^{52}$ergs and appears to occupy most of the interstellar volume in the region. We comment briefly on the positive feedback between massive star formation and a high-pressure interstellar medium, and speculate as to the origin of the 30 Doradus complex.

4. The Detection of X-ray Emission from the OB Associations of the Large Magellanic Cloud

Q. Wang and D.J. Helfand

ABSTRACT

A systematic study of the X-ray properties of OB associations in the Large Magellanic Cloud has been carried out using the data from the *Einstein* Observatory. Not unexpectedly, we find an excess of young, X-ray bright supernova remnants in the vicinity of the associations. In addition, however, we detect diffuse X-ray emission from over two dozen other associaitons; luminosities in the 0.16 – 3.5 keV band range from $\sim 3 \times 10^{34}$ (the detection threshold) to $\sim 10^{36}$erg s^{-1}. For several of the more luminous examples, we show that emission from interstellar bubbles created by the OB stellar winds alone is insufficient to explain the emission. We conclude that transient heating of the bubble cavities by recent supernovae is required to explain the observed X-rays and that such a scenario is consistent with the number of X-ray-bright associations and the expected supernova rate from the young stars they contain. The mean X-ray luminosity of the ~ 50 undetected associations is $\sim 10^{34}$erg s^{-1} and the emission from all associations contributes $\sim 4\%$ to the total diffuse X-ray emission from the galaxy.

5. LMC 2 as the Blow-out of a Hot Supergiant Bubble

Q. Wang and D.J. Helfand

ABSTRACT

Based on the data collected with the Imaging Proportional Counter (IPC) aboard the *Einstein* Observatory, we have discovered a bright extended X-ray emission region which is enclosed by the supergiant shell (SGS) LMC 2, as identified from optical and radio observations. The diffuse X-ray emission appears to come from hot gas in a corresponding hot supergiant bubble (SGB). The X-ray counting rate of the SGB is ~ 0.6 phs^{-1} in the IPC borad band (0.16 – 3.5 keV), corresponding to an X-ray luminosity of $\sim 10^{37}$erg s^{-1}. with an assumed gas temperature 10^7K. The area (~ 0.2 kpc^2) covered by the bright X-ray emission region correlates well with a cold-ISM cavity indicated in both HI and IRAS maps, but is smaller than the region bounded by the optical filaments.

We suggest that LMC 2 is created by the breakout of the SGB from the dense galactic plane of the Large Cloud. The bright X-ray emission arises in the plane, where the SGB is energized by stellar winds and supernova explosions. The blown-out portion of the SGB expands rapidly in the low density region away from the galactic plane; its boundary is marked by rim-brightened optical filaments in the interface between the hot interior and the cold shell. This is the first clear observational evidence of such a hot SGB in an external galaxy.